

GEOLOGY AND PHYSIOGRAPHY OF THE MOONLIGHT HEAD DISTRICT, VICTORIA

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Abstract

The lithology, distribution and stratigraphical relationships of Jurassic, Eocene, Pleistocene and Recent deposits are discussed, and a vertical stratigraphical column, based on coastal sections from Moonlight Head in the south-east to Peterborough, twenty miles west-north-west, has been prepared to indicate the approximate thicknesses of the various strata representing post-Jurassic sedimentation. The Eocene rocks constitute the south-easterly continuation of those already described from coastal sections extending north-westerly from Pebble Point to within half a mile of the mouth of the Gellibrand River. Additional information has been obtained on certain members of the Eocene strata, all of which are now grouped in the Wangerrip Formation. A fossil fungus is described from one member of the Eocene rocks. Australites are recorded from the Moonlight Head district. Slump terraces and erosion amphitheatres are characteristic features of the coastal physiography.

Introduction

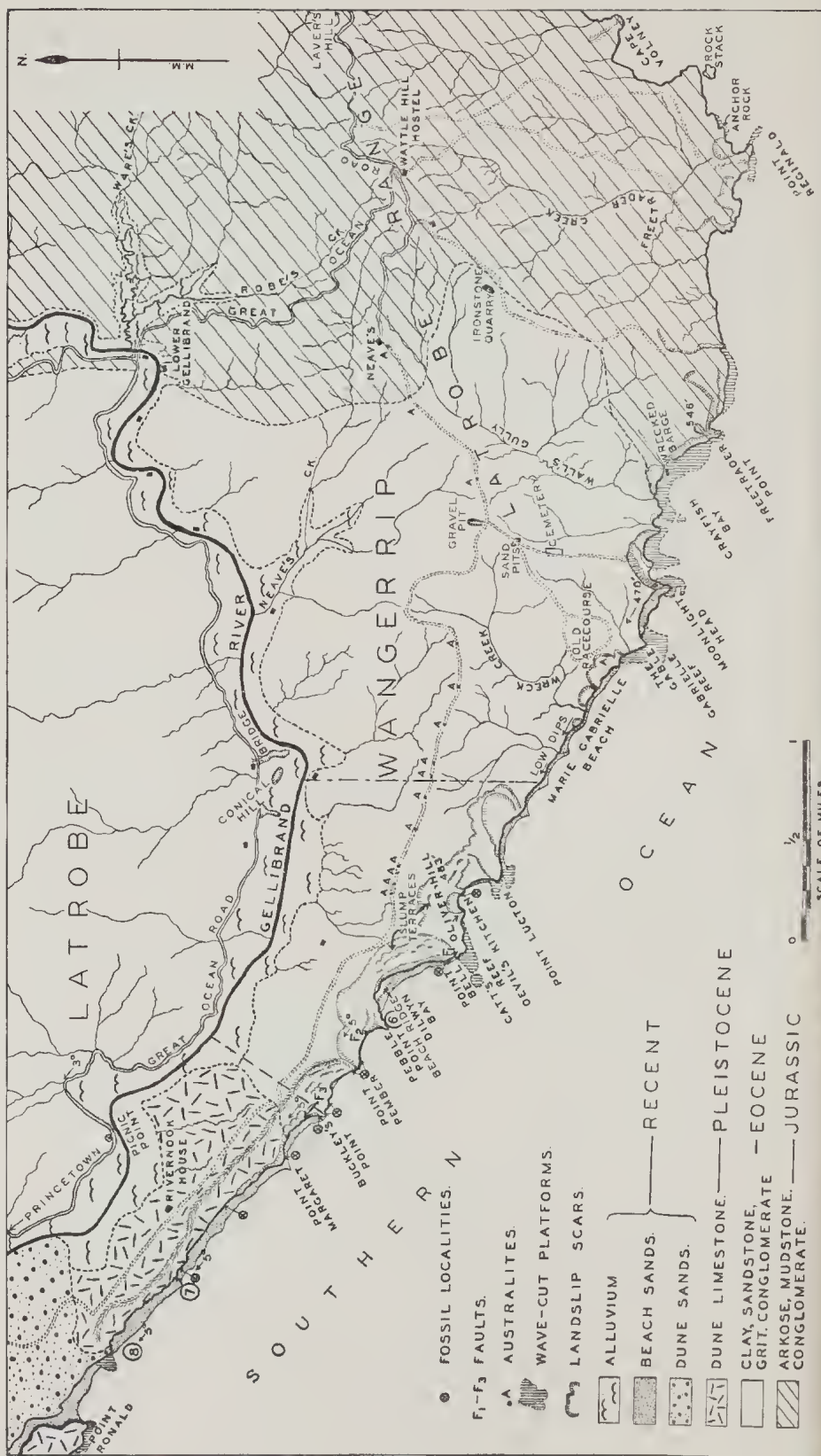
The Moonlight Head area, seven miles south-east of Princetown, and eleven miles south-west of Laver's Hill, lies on the south-west flanks of the Otway Ranges on the south coast of Western Victoria (Fig. 4). The area embraces parts of the parishes of Wangerrip and Latrobe (Fig. 1) in the counties of Polwarth and Heytesbury.

The limits of distribution of the geological formations shown in Fig. 1, are principally based upon evidence from coastal sections and from cuttings along the Great Ocean road. Inland exposures are sparse, and the older formations are covered by veneers of 'quartz drift' (i.e. late Cainozoic gravels, grits and sands), soils and alluvium, with dense, stunted vegetation in the hilly country, and deep gullies north and south-east of the lower reaches of the Gellibrand River.

For purposes of concise description and accurate location, it has become necessary to attach names to certain of the points, bays and gullies in the Moonlight Head area, as hitherto, many of these features were unknown by name, even to local inhabitants.

Localities referred to in previous papers (Baker, 1943a, Singleton, 1943 and Teichert, 1943) as the first, second and third points north-west of Pebble Point, are now named Point Pember, Buckley's Point and Point Margaret respectively. The position of Catt's Reef in Fig. 1 is not that marked on Wilkinson's original map (1865), as local inhabitants are unanimous in assigning the name 'Catt's Reef' to the reef off Pt. Bell; this position has been adopted herein. Wreck Creek is a local name for the creek that provides access down steep, bold cliffs to the reefs on which the barque *Marie Gabrielle* was wrecked on 25/11/69 and the barque *Fiji* on 6/9/91. The long beach extending for half-a-mile south-east and one mile north-west of Wreck Creek, has been appropriately named 'Marie Gabrielle Beach'.

General access to the area is gained via an old road near the coast, which connects Wattle Hill Hostel and Rivernook House. It is passable only from Wattle Hill Hostel to one mile west of Neave's farm, and follows the crest of a ridge between the sea cliffs and the valley of the Gellibrand River, thus conforming with the track cut by Wilkinson's survey party in 1863-4. Access



to the coastal sections is difficult in most parts, owing to the precipitous character of the sea cliffs, but is possible down landslides in the erosion amphitheatre south-west of the Old Racecourse at Moonlight Head, down Wreck Creek, or down landslides at the Devil's Kitchen and at the head of Dilwyn Bay. Only under favourable tidal conditions can Pebble Point be reached along the foreshore from either the north-west or south-east sides. Tidal conditions and deep water limit approach to many other cliff sections between Buckley's Point and Cape Volney.

Geology of the Area

JURASSIC

MOONLIGHT HEAD BEDS

The Jurassic rocks in the Moonlight Head area constitute the south-western extremity of the rocks of this age composing the Otway Ranges (Fig. 4). They form bold headlands and steep cliffs along the coast from the vicinity of Freetrader Point to the eastern limit of the map (Fig. 1), and occur beneath the Tertiary deposits in the coastal sections from the head of Crayfish Bay to Point Margaret. In the eastern parts of the area, the Jurassic is exposed in road cuttings from a little west of Lower Gellibrand to beyond Wattle Hill Hostel. All of these exposed Jurassic rocks are herein classed as the Moonlight Head Beds.

According to Murray (1877, p. 132), thick-bedded Jurassic sandstones predominate from the Johanna River (9 or 10 miles east of Moonlight Head) to the last appearance of the Jurassic rocks a mile or so south-east of the mouth of the Gellibrand River. These sandstones, which constitute the greater part of the Moonlight Head Beds (Fig. 2), have recently been described as arkoses of lacustrine origin (Edwards and Baker, 1943). They are massive and of light greenish-grey colour, with occasional interbedded mudstones as at the Devil's Kitchen and rare runs of conglomerate, e.g., N.W. of The Gable. Fossils are few, and represented by coalified plant fragments in the arkoses, and poorly preserved leaf impressions in the mudstones.

Dips in the Moonlight Head Beds are principally in a westerly to south-westerly direction at angles of 15° in the Moonlight Head area, decreasing to 10° in a north-westerly direction. The arkoses are strongly current-bedded in parts. Calcareous cannon-ball concretions are common. Flat-lying lenticular concretions (along bedding planes) weather out as projecting, low-dipping ledges from the cliff faces as at Buckley's Point, while thin, vertical seams (along joint planes), stand out as narrow columns as at Point Lucton. The arkoses are also rich in calcareous cement, indicating their high degree of porosity on burial. They differ somewhat from the normal Victorian Jurassic arkoses in having a coarse 'pepper and salt' appearance. This results from the presence of darker grains of hornblende and small, dark-coloured grains (of the same size), of various rock fragments, set in a greenish-grey matrix, especially in the fresher arkoses of the cliffs around Pebble Point, Devil's Kitchen and along Marie Gabrielle Beach.

The detailed mineralogy of the arkoses has been dealt with elsewhere (Baker, 1943a and Edwards and Baker, 1943, pp. 199, 201 and 203).

A number of quartz reefs striking N. 10° W. and up to 3 feet wide, have been recorded as cutting through the Jurassic rocks (Stirling, 1898). They occur in allotment 3A, parish of Wangerrip, $2\frac{1}{4}$ miles north of Lower Gellibrand. Although auriferous, they are not payable reefs. Little is known of their nature or origin; according to Stirling (1898, p. 92), they are 'associated with eruptive dykes'. The main interest lies in the fact that these auriferous quartz

reefs are of post-Jurassic age. They are probably pre-Eocene, because, although not observed in contact with Eocene rocks, reef quartz pebbles and grains in the basal members of the Wangerrip Formation, were probably derived, in part, from these reefs.

EOCENE

WANGERRIP FORMATION

Most of the Older Tertiary sediments situated south-east of Princetown, including the Pebble Point Beds, the Rivernook Bed, the Turritella Bed, the Trochocyathus Bed and the associated, interbedded clays (see Fig. 2), are now grouped into the Wangerrip Formation. The Wangerrip Formation is regarded as of Eocene age, although Singleton (1943, p. 277) suggested the possibility of the lower members (i.e. the Pebble Point Beds) being as old as Paleocene.

In the Moonlight Head area, the rocks of the Wangerrip Formation are lithologically comparable to and contiguous with the Eocene sediments already described from the coastal sections further to the north-west (Baker, 1943a). They represent higher horizons than the fossiliferous Pebble Point Beds, because, as far as can be ascertained, only the non-fossiliferous ferruginous grits, ferruginous sandstones and copiapite-bearing clays of the Wangerrip Formation are represented between Point Lucton (see Fig. 1) and Moonlight Head.

In the Eocene strata immediately south-east of Pebble Point, fossiliferous rocks are difficult to obtain *in situ*, because of the inaccessibility of the deposits, which occur high up in the steep cliffs. Recourse has therefore to be made to fallen blocks of Eocene strata. In this way, corals, pelecypods, decapod crustaceans and occasional sharks' teeth have been obtained on the north side of Point Bell and at the head of the bay locally known as the Devil's Kitchen, but the shelly fossils there are usually more fragmentary than those found north-west of Pebble Point; they occur principally in coarse, greenish-coloured quartz grits. On the south-east side of Pebble Point itself (Plate II, Fig. C), molluscs such as *Lahillia*, *Cucullaea* (Singleton, 1943) and *Eutrepheceras* (Teichert, 1947a), decapod crustaceans such as *Callianassa* (Glaessner, 1947), fish vertebrae, sharks' teeth and fossil wood occur *in situ*, for here the fossiliferous Eocene strata have been brought down almost to sea level by a small normal fault (F_1 on Fig. 1) with a north-north-westerly throw of approximately 35 feet. From Point Lucton easterly, however, none of the Eocene strata that can be examined *in situ* yielded fossils; moreover, fallen blocks of Eocene sediments on the nearby beaches are unfossiliferous, except for a few with *Callianassa* burrows near Point Lucton.

Lithologically, the Eocene sediments consist of littoral, shallow water deposits, such as conglomerate, coarse grits, sandstones (some gritty, some carbonaceous and some ironstained) and ironstones that are overlain by, and in part interbedded with clays containing gypsum and copiapite.

The conglomerate occurs locally in the Pebble Point Beds only, small pockets up to one foot thick being associated with fossiliferous grits, containing clay streaks, on the south-east side of Pebble Point, and at the head of the bay north-west of Pebble Point.

Some of the ironstone, e.g., that south-east of Neave's farm, (see Ironstone Quarry in Fig. 1), has been quarried for local use on the roads.

PEBBLE POINT BEDS

The conglomerates in the Pebble Point Beds contain a varied assemblage of well-rounded pebbles of rock types such as green, dense, flow-banded rhyolite, patinated flint, dark, dense hornfels, lydian stone, quartzite and various porphyries, etc. Most of these are alien to the rocks of the district, while many

of the lava and porphyry rocks are of types untraceable to any particular outcrops in Victoria. Some larger blocks of Jurassic sediments are incorporated in the Eocene conglomerate, and consist of arkose and plant-bearing mudstone blocks of more angular character and up to four feet across; they were derived from the Moonlight Head Beds. Among the exceptionally well-rounded constituents of the Eocene conglomerate are pebbles of buff-coloured siderite with thin limonitic coatings, characteristically well-polished and showing typical 'bread-crust' cracks; these were probably derived from the Jurassic sediments, as siderite nodules are known from the Jurassic coal measures at Wonthaggi in South Gippsland.

The grits in the Pebble Point Beds are quartz grits of moderately coarse texture grading in parts into gritty sandstones and coarse, ironstained sandstones. The fossiliferous portions of the grits vary in colour from green in the fresher varieties to brown and yellow where oxidised, but the non-fossiliferous grits are invariably dark brown because of the presence of abundant limonitic cement. A characteristic feature of many parts of the grits, is the abundance of relatively narrow, branching, nodule-like structures which have been recently interpreted by Glaessner (1947) as *Callianassa* burrows.

In thin section, fossiliferous grits from the Devil's Kitchen show abundant angular and sub-angular quartz grains, occasional muscovite and chlorite, and rare hornblende. These, with numerous fragments of fossils, are set in a base that is principally calcareous with some accompanying siderite; parts of the matrix are, however, composed of argillaceous material and glauconite. The glauconite is often present in the form of pellets, and sometimes alternates with layers of calcite around glauconite and other centres in oolitic fashion. Very little feldspar from the Jurassic arkoses of this area, has survived weathering and transportation into the sediments of the Wangerrip Formation. One large, rounded poikilitic feldspar occurs in one thin section of grit, also rare angular grains of quartzite and staurolite schist.

The acid (HCl) soluble portion of the fossiliferous grits, is composed principally of calcium- with some iron-carbonate, and constitutes 38.5% of the sediment. The light, insoluble fraction amounts to 60.3% and the heavy minerals (separated in bromoform of specific gravity 2.88) amount to 1.2%. The heavy minerals are magnetite, ilmenite, pyrite, leucoxene, brown and blue tourmaline, rutile, zircon, hornblende, epidote, cyanite, andalusite, cassiterite, garnet, brookite, greenish-blue spinel, staurolite and zoisite.

Narrow bands of black, sandy and gritty clays, interbedded with the ferruginous and green grits of the Pebble Point Beds, are exposed on parts of the wave-cut platforms and in the lower parts of the sea cliffs at Point Bell. They contain abundant carbonaceous material, large grains of reef quartz up to 8 mm. across, a considerable amount of finer quartz sand, some copiapite, scattered flakes of selenite and rare feldspar. The rock is friable and breaks down readily in water. Apart from small fragments of wood, no other macro- and no micro-fossils were detected in deposits of this character, and there was only slight effervescence with acids, indicating little carbonate matter. Finer quartz sand in the rock is of relatively even grade size, and the grains rounded to sub-angular. Although the heavy mineral residues from this type of sediment are small in amount (enough to prepare one slide mount from one hand specimen), they are nevertheless relatively rich in mineral species. The assemblage is practically the same as that of the green, fossiliferous grits from the Devil's Kitchen; the several colour varieties of tourmaline, including rubellite and indicolite, are the same, likewise types of zircon crystals and other diagnostic mineral species.

The provenance for these rocks from the Devil's Kitchen and from Point

Bell (rocks that are separated stratigraphically by only a few feet, and both of which belong to the Pebble Point Beds), is of considerable interest, and probably applies in general to much of the Wangerrip Formation. In the first place, the absence of a shelly fauna from the black, sandy and gritty clays from Point Bell, is due to conditions entirely unfavourable for animal life. Much carbonaceous matter, associated with finely divided sulphides, created toxic conditions and shortage of oxygen, producing an environment deleterious to animal life. Apparently much debris in a finely comminuted state was swept into this area from a nearby coast. Such conditions were repeated several times during the early periods of Eocene sedimentation, with a relatively clear water environment developed at least once, to allow of the existence of organisms now represented in the fossiliferous grits.

In the second place, the area undergoing erosion was subjected to occasional heavy rainfall, and a vigorous drainage system was formed, capable of transporting quartz grains of considerable grade size (8 mm.) into the theatre of sedimentation. In the third place, the nature of the rocks comprising the terrane in early Eocene times, is indicated by the character of the heavy minerals in the grits and gritty clays. The relative abundance of cassiterite and the several varieties of tourmaline, together with topaz and the very abundant quartz grains, show that a granitic cupola was undergoing active erosion. This cupola was not very far from the shoreline, because the crystal outlines are particularly well preserved. The existence of rounded tourmaline grains in the heavy mineral assemblage of the basal Eocene beds, points to the fact that well abraded tourmaline had been swept into the Eocene from rocks representing an earlier cycle of erosion, transportation and sedimentation : such sediments probably constituted a part of the original country rocks into which the granitic magma was intruded. Minerals carried into the Eocene basin of sedimentation, from the thermo-metamorphic province of this postulated granite cupola, are andalusite, spinel, rutile and brookite. The granitic mass itself contributed many of the translucent and sub-angular quartz grains and all of the zircons with well preserved crystal outlines. A few, rounded zircon grains present in the Eocene, represent types derived either from the pre-granite sediments, or, perhaps with hornblende, from any Jurassic arkoses that were exposed in the terrane.

The existence of schists or gneisses as outcrops in the Eocene landscape, is suggested by the presence in the Eocene grits of strained quartz crystals, cyanite, staurolite and garnet, although some of the garnet may have been weathered out from Jurassic rocks. Associated quartzites were also present, as evidenced by the occurrence of grains of this rock in the Eocene grits. The types of tourmaline in the basal Eocene sediments are such as to indicate granitic, pegmatitic, sedimentary and pegmatized injected metamorphic terranes (cf. Krynine, 1946). The pyrite in the sediments is authigenic and occurs as round pellets and clusters of minute crystals. It probably represents, in part at least, sulphide residues from the decomposing vegetable matter swept into the Eocene basin of sedimentation. A number of the heavy mineral grains have acted as centres of deposition for glauconite, which forms complete sheaths around some of them. Rare flakes of white mica in the heavy mineral assemblage are of a type suggestive of origin from gas fluxing effects bleaching the original biotite in the granitic cupola. Their sparsity in the grits results from strong currents carrying them further out into the deeper portions of the Eocene basin of sedimentation (cf. Rivernook Bed and Clays of the Wangerrip Formation).

There is no evidence to indicate the particular direction of this portion of the Eocene terrane from the basin of sedimentation, but as the necessary rock

types do not occur on the present elevated portions of Victoria, a terrane of the type indicated may have lain either to the south or south-west, in a region now submerged beneath the Southern Ocean, or to the north in a region now covered beneath the lava flows of the basalt plains. Associated with the rocks of the terrane were abundant quartz reefs: from these were obtained the bulk of the rounded reef quartz pebbles and gravel granules so plentiful in the Pebble Point Beds. The reef quartz pebbles are far too abundant to have all come from the limited number of narrow quartz reefs that traverse the Jurassic rocks of the Moonlight Head district.

Although the heavy mineral suites of the Eocene grits and gritty clays have several characteristics in common with the nearby Jurassic rocks which formed the coastal area of the time, and which supplied some of the disintegration products that found their way into the Eocene rocks, the above facts indicate several significant changes in mineralogy in crossing the Eocene—Jurassic boundary, and these differences can only be explained in terms of the presence, in portions of the Eocene terrane, of rock types with different mineral constituents from the Jurassic; moreover, outcrops of such rock types were being subjected to very active processes of erosion and transportation.

RIVERNOOK BED

The Rivernook Bed, which outcrops on the coast south of Rivernook House (Fig. 1), has so far been little studied, because of frequent and prolonged masking of the outcrop under beach sands. It occurs about half way up from the base of the Wanggerrip Formation, and is interbedded with Eocene clays carrying copiapite, gypsum, pyrite and rare fragments of fossils (Baker, 1943a, p. 248). It is regarded as of Eocene age for reasons given in an earlier publication (Baker, 1944, p. 86). Further information concerning the Rivernook Bed is now to hand as a result of exposure of several square yards of the deposit after the occurrence of small landslides following the heavy rains in the early part of 1946.

The deposit is best described as a glauconitic clay sediment. The glauconite is present mainly in the form of ovoid-shaped pellets ranging up to 1 mm. in size, and sub-spherical grains up to $\frac{1}{2}$ mm. across. Where associated with concentric layers of calcite, the glauconite pellets tend to be oolitic in character, but several examples are like those described by Edwards (1945) from the glauconitic sandstone in the Tertiary of East Gippsland (Eastern Victoria), being derived from the alteration of biotite flakes. Most of the glauconite has been altered to a ferruginous clay-like substance, mainly as a result of weathering.

The rock is porous in parts, and contains abundant greenish-brown argillaceous material in which small plates and fine needle-like crystals of gypsum are common. Parts are strongly consolidated, with patches rich in pyritic and calcareous matter, the pyrite occurring as small clusters of crystals of microscopic size, showing cube, cube and pyritohedron, and octahedron modified by the cube. The pyrite occasionally replaces and infills micro-fossil structures. Fine, slender echinoid spines are present. Quartz is a common constituent, mostly as sub-angular grains of the $\frac{1}{2}$ mm. grade size; sub-angular grains up to 2 mm. across are rare. Felspar is an occasional constituent; muscovite plates are more frequent than in the Pebble Point Beds. Yellow, reddish- and brownish-coloured fragments and small, rounded balls of fossil resin are features of the Rivernook Bed. The resin is partly opaque, but mainly translucent, and is fluorescent in pale sulphur-yellow colours under ultra-violet radiation.

The general characteristics of the Rivernook Bed resemble those of the amber-bearing beds of East Prussia described by Tornquist (1910, p. 83). In

East Prussia, the clayey-glaucinitic sandstone deposit is similarly blue-green, micaceous, rarely calcareous, strongly consolidated in parts only, and contains amber and a marine fauna (regarded by Tornquist as of Lower Oligocene age). A marine fauna is also found in the Rivernook Bed, this fauna consisting of foraminifera, corals, pelecypods, gasteropods, scaphopods, sharks' teeth and thalassinid macrurous crustacea such as *Callianassa* sp. and *Ctenocheles victor* Glaessner. Many of these fossils resemble species in the Pebble Point Beds.

A feature of the argillaceous portions of the deposit, is the occurrence of rods of clay up to $\frac{3}{4}$ inch in diameter, sometimes 9 inches long and longitudinally marked with shallow, parallel, unevenly spaced striae, some of which are slightly deeper than others. The rods show no internal structure apart from incorporated pellets of glauconite. They cut across bedding planes and usually terminate in depth with a distinct taper and occasionally a slight curvature away from the long axis of the rod. The rods appear at first to represent the burrows of mud-haunting organisms, but the striations resemble more the markings characteristic of slickensided surfaces. That they are most likely slickensided surfaces, is borne out by the occurrence of similar markings on broader and flatter planes elsewhere in the deposit, more particularly along joint planes. The striated surfaces evidently resulted from slight slipping of the clay after lubrication on wetting of this coastal exposure, and the striae would be made by the movement of either the smaller glauconite pellets in the rock, or more likely by the edges of the smaller of the sub-angular grains of quartz.

Concretions and harder bands of the deposit are richly calcareous, with traces of P_2O_5 . The fine, light fraction of the sediment consists of quartz, white mica, macerated plant debris, resin and rare micro-organisms. The heavy residue is principally composed of pyrite and bleached biotite, the abundant flakes of mica having been floated out into the deeper parts of the Eocene basin of sedimentation. Other heavy minerals are very scarce, there being but one or two grains or flakes of each of the minerals brown biotite, chlorite, prismatic zircon, prismatic cassiterite, hornblende, tourmaline and andalusite; a little siderite was also detected.

Among the carbonaceous products in the Rivernook Bed, are indeterminable lignified particles, fragments with poorly preserved cell structures and one piece of cuticle (which appears to be monocotyledonous) containing the fruiting stage of a fossil fungus of the downy mildew type (Plate 1c). From the evidence available, this fungus belongs to the class Phycomycetes in the Eumycetes (True Fungi). It probably belongs to the order Peronosporales, exhibiting a strong family likeness to the genus *Peronospora*. The hyphal filaments are non-septate, dichotomously branched with blunt tips, and just under 4μ in width. The reproductive bodies (dark, rounded areas in Plate 1c) are ovoid, being 0.03 mm. long and 0.02 mm. wide. The smaller bodies in the cuticle are 0.006 mm. in diameter.

Parasitic fungi of this character have been described from the Coal Measures in other parts of the world. Hyphae have been recognised on the stems of *Lepidodendron*, on the leaves of *Cordaites* and *Sphenopteris*, as a sub-epidermal disease on the leaves of *Neuropteris* and in the outer layers of roots. Fossil Peronosporae have also been described by Carruthers (1876) and Smith (1877) (*P. antiquarius*) in the tracheids of species of *Lepidodendron* from the English Coal Measures, and Pampaloni (1902) has described *Peronosporites miocenicus* and *P. siculus* from the Middle Miocene of Sicily.

The Rivernook Bed thus contains an association of a marine fauna and a mineral of marine origin (glauconite) with terrigenous deposits containing fossil resin, a fossil terrestrial fungus and abundant carbonaceous material. The area of sedimentation therefore apparently lay fairly close inshore and

experienced generally shallow water conditions, although somewhat deeper than areas where the littoral grits of the Pebble Point Beds were formed. The terrane was apparently well-wooded, with plant debris liberally scattered over an area subjected to good drainage conditions and having a moist, not very warm climate (*Peronospora* being a pathogen requiring such conditions). From this area the plant debris was swept into the Eocene sea, larger twigs and fragments of small branches of wood (undetermined), being dropped nearer inshore and incorporated in the littoral, fossiliferous grits. Finer, comminuted woody and leafy tissues and considerable amounts of macerated plant debris were carried further offshore to be deposited more slowly under somewhat deeper-water conditions, and intermingled with the remains of marine organisms and with glauconite pellets which were being produced on parts of the sea bed.

CLAYS OF THE WANGERRIP FORMATION

The clay deposits of the Wangerrip Formation, together with intercalated fossiliferous sandstone beds referred to as the *Turritella* Bed and the *Trochocyathus* Bed, have been described elsewhere (Baker, 1943a, pp. 241 and 247-8), and no further information has been obtained concerning them. Fossils from these beds, mainly the *Turritella* Bed and the *Trochocyathus* Bed, and from stratigraphically lower members of the Wangerrip Formation, such as the Pebble Point Beds, all now regarded as of Eocene age, have been determined from time to time by Duncan (1870), Dennant and Kitson (1903), Dennant (1904) and Chapman (1904 and 1924), while recent determinations have been made by Singleton (1943), Teichert (1943), Glaessner (1947), Parr (appendix-Baker, 1943a), and Teichert (1947a).

In the road cuttings north of the coastal sections, the Older Tertiary rocks are much iron-stained and superficially decomposed. They were recently (Baker, 1943a) referred to the Eocene on lithological analogy with the fossiliferous Eocene deposits in the coastal sections. Their Eocene age is now confirmed by the discovery (early in 1946) of weathered fossiliferous beds in a road cutting on a bend in the Great Ocean road near Picnic Point (see Fig. 1), half a mile north-east of Rivernook House. The beds here are ferruginous sandy clays containing *Trochocyathus* and occasional gasteropods analogous with those of the *Trochocyathus* Bed (specimen locality 7 on map, Fig. 1) in the coastal sections nearly one mile to the south-west of Picnic Point. This occurrence lies on the northeast-southwest line of strike of the Eocene deposits of the area. Road cuttings and small quarries east of this locality, also reveal ferruginous Eocene rocks, but they have so far proved barren of fossils.

DISPOSITION OF EOCENE BEDS AND RELATIONSHIP TO JURASSIC ROCKS

The Eocene deposits occur in a conformable formation (the Wangerrip Formation), in which the beds overlap to the south-east on to an erosion surface in the Jurassic bedrock. Whereas the Eocene sediments dip north-westerly at low angles (5°) off the Jurassic strata, so that they come down to sea level in the Pebble Point-Point Margaret area (Plate III, Figs. A and B), and are exposed along coastal sections trending north-westerly from this point, to the south-east, they rise gradually from fifty feet above sea level in the neighbourhood of Point Bell (Plate II, Fig. B) to 300 feet or so above sea level in the bold headland forming Moonlight Head (Plate II, Figs. D and F), just over two miles south-east of Point Bell.

The gradual rise is due to the 10° slope of the old erosion surface in the Jurassic rocks exposed between Point Lucton and Moonlight Head. A little over half a mile east of Moonlight Head (see Fig. 1), Eocene sediments disappear

from the higher parts of the coastal sections, and from here (at the head of Crayfish Bay), through Free trader Point and on to Cape Volney, the sea cliffs are cut in Jurassic rocks.

The older fossiliferous members of the Wangerrip Formation, i.e., the Pebble Point Beds with the associated lenticular conglomerate, do not appear in the south-east because of the south-easterly transgressive overlap on to the sloping Jurassic erosion surface; they are last met with in a south-easterly direction at the head of Devil's Kitchen.

The dips of the Eocene deposits, which are low even at their maximum values in the outcrops in the north-westerly part of the area, become still lower in the south-east, and from Point Lucton to their eastern limits at the head of Crayfish Bay, they depart very little from the horizontal; the few low dips shown are again in a north-westerly direction. Along the south-easterly parts of the coastal exposures of the Eocene sediments, the deposits are some 200 to 250 feet thick, and so if the younger members of the Wangerrip Formation (i.e. those occurring north-west of Point Margaret) were ever represented in the Point Lucton-Moonlight Head sections, then something like 600 feet of the Eocene rocks have been removed by erosion.

The sequence of deposits set out by Stirling (1898) for the Moonlight Head cliff section is shown in Table I.

TABLE I.

3 feet—	pisolitic iron ore and surface sandy clays.
15 feet—	pipeclays and mixed clays.
2 feet—	ferruginous grits.
10 feet—	sandy clays and fine grit.
40 feet—	blue-red mudrock seamed with yellow sulphate of lime.
10 feet—	ironstone cement, light boulders and gravel.
90 feet—	mixed clays, sandy clays and gravel.
20 feet—	decomposed Jurassic sandstone and slate.
300 feet—	Jurassic sandstone.

The cliff section at Moonlight Head itself is inaccessible for close inspection of the Eocene rocks. Presumably the above sequence was obtained from more accessible sections in the steep slopes at the head of the erosion amphitheatre south-west of the Old Racecourse near Moonlight Head (see Fig. 1). The Eocene deposits of these coastal sections correspond to that portion of the clay series of the Wangerrip Formation that rests on the fossiliferous Pebble Point Beds and underlies the Rivernook Bed (see Fig. 2). The three feet of pisolitic iron ore and surface sandy clays referred to by Stirling at the top of the section (Table 1), represent the various soil horizons with buckshot gravel, while the yellow sulphate of lime referred to in the 40 feet of blue-red mudrock, is copiapite.

The surface of unconformity between the Jurassic and Eocene sediments in the vicinity of Moonlight Head, is relatively even in character (Plate II, Figs. D and F). Minor irregularities are caused by slight undulations of the old erosion surface (like that in Plate IV, Fig. A), and the occasional penetration of the constituents of the Eocene deposits along cracks trending down from the surface of the Jurassic. The surface appears to be one of marine denudation with structures such as that in Plate IV, Fig. A, representing infilled pot-holes, (the direction of the currents in this instance were apparently from left to right).

The Eocene rocks stretch for five miles along the coastal sections south-east of the mouth of the Gellibrand River, extending from about $\frac{3}{4}$ mile south-east of the river mouth to Crayfish Bay (Fig. 1). For nearly half of this distance, they dip at 5° to the north-west (see dip values on Fig. 1) in a conformable sequence (i.e., as far as masking by landslides permits of observation), and

should therefore be approximately 900 feet thick, if such dips are maintained, as they are assumed to be herein.

FAULTING

The assumed value for the total thickness of the Eocene sediments on the above basis, has to be modified in view of the occurrence of minor normal faults at the positions marked as F_1 , F_2 and F_3 on the map (Fig. 1). These occur on the north side of Point Bell (Plate IV, Fig. B) = F_1 ; a short distance north-north-west of Pebble Point = F_2 , and on the bayside between Buckley's Point and Point Margaret (Plate II, Fig. A) = F_3 . Two small normal faults form a ridge fault in Jurassic rocks on the east side of the Devil's Kitchen; they have small throws and their effect cannot be observed on the Eocene here, because of its height in almost vertical cliffs.

F_1 , a dip-slip oblique fault, has a throw of some 35 feet with the downthrow to the north-north-west. The Eocene deposits on the downthrown side of this fault show minor amounts of drag along the fault plane, while a narrow zone of mylonite occurs between the Jurassic and the Eocene rocks at the fault junction. This fault passes up into a small monoclinal fold, and then rapidly dies out vertically. The faulting here has resulted in little disturbance of the angle of dip of the sediments.

F_2 , situated about 100 yards north-west of Pebble Point, is a high-angle, dip-slip oblique fault, hading to the south-south-east, and with a throw of 25 to 30 feet. The Pebble Point fault and the Point Bell fault together form a small trough in the Eocene sediments, as their hade are opposed. On the upthrown side of the Pebble Point fault (F_2), the dip of the Eocene is 5° to the north-west, while on the downthrown side, a small dip south-easterly off the fault plane is but a minor feature, and probably due to drag along the fault plane; the result, however, has been to form a small local synclinal sag.

F_3 is a dip-slip dip fault, in which greenish-grey arkoses are brought up against the copiapite-bearing carbonaceous clays of the Eocene (Plate II, Fig. A) and the Jurassic rocks have been locally brecciated.

Taking into account the effects of these minor faults in assessing the probable total thickness of the Eocene sediments of the whole area, it has been concluded, as set out in Fig. 2, that the Wangerrip Formation has a thickness of between 800 and 850 feet.

RECORDED FOSSIL CONTENT OF THE WANGERRIP FORMATION

FORAMINIFERA—from the Pebble Point Beds.

- Dentalina* sp.
- Nodosaria* sp.
- Vaginula* sp. aff. *subplumoides* Parr.
- Marginula* aff. *costata* (Batsch).
- Marginula* aff. *glabra* d'Orbigny.
- Lenticulina* spp.
- Planularia* sp.
- Lagena hexagona* (Will.).
- Lagena catenulata* (Will.).
- Globulina gibba* d'Orbigny.
- Guttulina problema* (d'Orbigny).
- Guttulina lactea* (Walker and Jacob).
- Guttulina* sp.
- Angulogerina* aff. *elongata* (Halkyard).
- Eponides obtusus* (Burrows and Holland) var. *westraliensis* Parr.
- Gyroïdina* aff. *octocamerata* Cushman and Hanna.
- Pulvinulinella* sp. nov.
- Baggatella* sp. nov.
- Ceratobulimina* spp. nov.

Anomalina sp. nov.
Anomalina cf. *glabrata* Cushman.
Cibicides cf. *lobatulus* (Walker and Jacob).
Cibicides spp.
Globigerina sp.

ANTHOZOA—from the Trochocyathus Bed.

Cycloseris tenuis Duncan.
Trochocyathus victoriae Duncan.
Trochocyathus wilkinsoni
Trochocyathus meridionalis Duncan.
— from the Rivernook Bed.
Flabellum microscriptum Dennant.
Flabellum candeanum Edw. and Haime.

ECHINOIDEA — from a hard band in clays above the Pebble Point Beds.

Schizaster sp.
— from the Pebble Point Beds and clays of the Wangerrip Formation.
Echinoid spines.

BRYOZOA—from the Pebble Point Beds and clays above them.

Bryozoan fragments.

PELECYPODA—from the Pebble Point Beds.

Nuculana paucigradata Singleton.
Cucullaea (*Cucullona*) *psephea* Singleton.
Limopsis sp. nov. (?).
Lahillia australica Singleton.
Eotrigonia sp.

SCAPHOPODA—from the Pebble Point Beds.

Dentalium (*Fissidentalium*) *gracilicostatum* Singleton.

GASTEROPODA—from the Turritella Bed.

Turritella sp. (?).

NAUTILOIDEA — from the Pebble Point Beds.

Aturoidea distans Teichert.
Eutrephecerus victorianum (Teichert).

DECAPOD CRUSTACEA—from the Pebble Point Beds.

Callianassa bakeri Glaessner.
Callianassa cf. *lacunosa* Rathbun.
— from the Rivernook Bed.
Callianassa sp.
Ctenocheles victor Glaessner.

OSTRACODA—from the Pebble Point Beds.

Species of Ostracods.

VERTEBRATA—from the Trochocyathus Bed.

Odontaspis cuspidata (Agassiz).
Isurus minutus (Agassiz).
— from the Pebble Point Beds.
Odontaspis sp.
Isurus sp.
Fish vertebrae and otoliths.
Whalebone fragments.
— from the Rivernook Bed.
Odontaspis sp.

PLANTAE—from the Pebble Point Beds.

Fossil wood (undetermined).
— from the Rivernook Bed.
Fossil fungus referable to the Peronosporales.

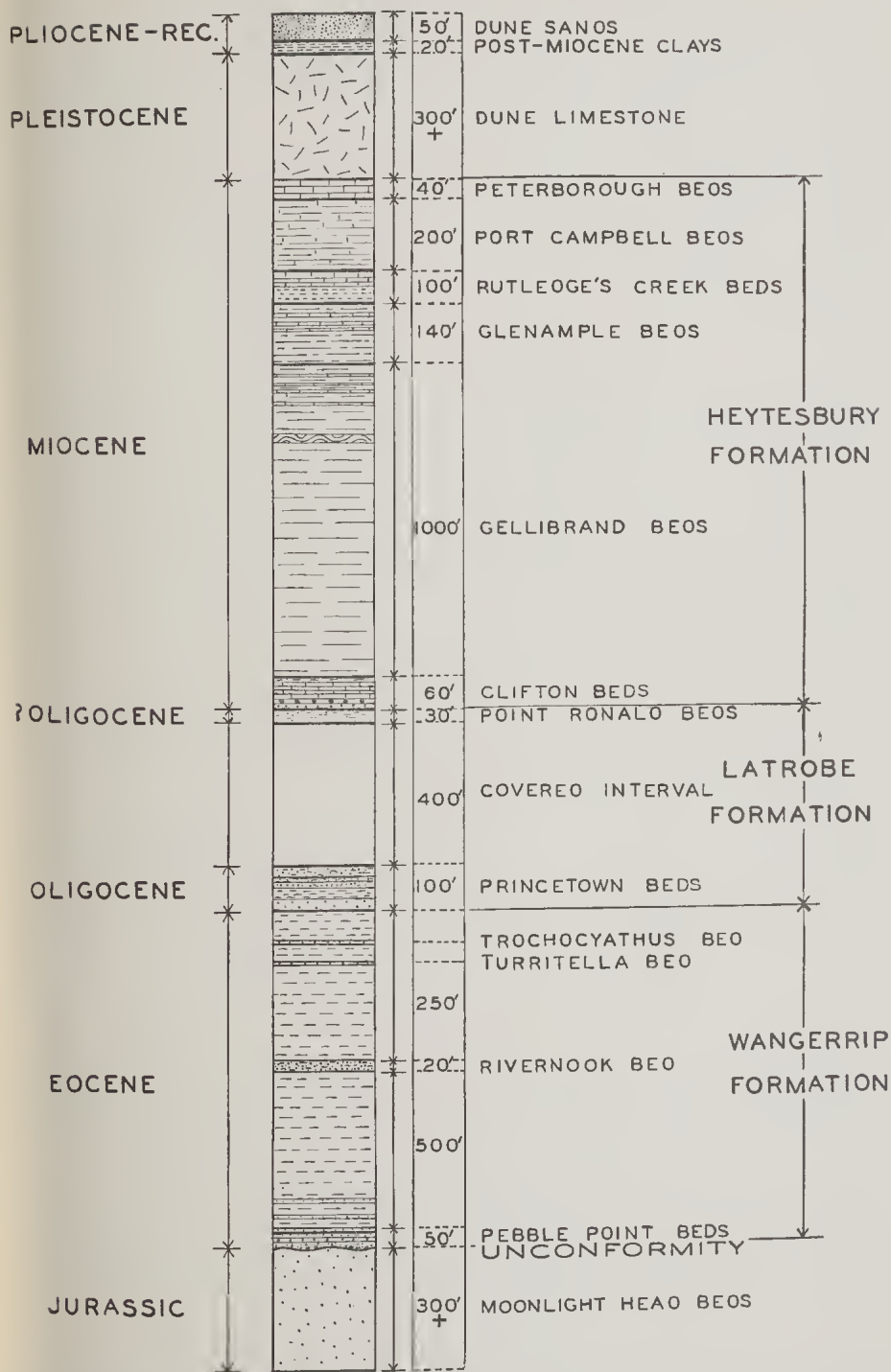


Figure 2. Vertical column representing Tertiary sedimentation west of the Otway Ranges, to Peterborough.

RELATIONS OF THE EOCENE TO YOUNGER CAINOZOIC SEDIMENTS

The Eocene in the north-west portion of the area, is conformably overlain by non-fossiliferous deposits constituting the Princetown Beds which occur at the base of the Latrobe Formation, and are regarded as probably being of Oligocene age (Baker, 1944, p. 87). The Tertiary sequence north-westward from the mouth of the Gellibrand River through Port Campbell to Peterborough, has been discussed in previous articles (Baker, 1943a, 1944 and 1945b). In order to bring together, in summarised form, the relationships of Tertiary rocks represented in coastal sections stretching from Crayfish Bay, near Moonlight Head in the south-east, along just over twenty miles of coastline to Peterborough in the west-north-west, a sedimentation table is presented in Fig. 2.

For the purposes of the table (Fig. 2), it has been assumed that similar local dips (up to 5° in the same direction) are maintained throughout the Tertiary rocks between and including the Pebble Point Beds and the Glenample Beds without any major interruption due to the small faults in the vicinity of Pebble Point. In like manner, for reasons already published (Baker, 1944, p. 87) it is assumed that similar dips prevail throughout the covered interval (Fig. 2). Because of the slight transgressive overlap of the oldest exposed Eocene deposits in the area, it is conceivable that still older members of the Eocene might exist at depth in the north-west, below the Pebble Point Beds.

New names introduced for some of the beds set out in Fig. 2, are described in the following list :

WANGERRIP FORMATION. Dealt with in the preceding text.

LATROBE FORMATION. A group of beds conformable in themselves and with the older Wangerrip Formation and apparently also conformable to the younger Heytesbury Formation.

The *Princetown Beds* are the unfossiliferous sediments south-east of the mouth of the Gellibrand River, which conformably overlie the uppermost member of the Wangerrip Formation, and are regarded tentatively as of Oligocene age. They are overlain in the north-west by Pleistocene dune limestone which occupy the major part of the covered interval.

The *Point Ronald Beds* are the unfossiliferous sediments half a mile north-west of Point Ronald, situated on the right bank at the mouth of the Gellibrand River ; they are conformable with the overlying Clifton Beds.

HEYTESBURY FORMATION

The *Clifton Beds* at the base of the Heytesbury Formation, are fossiliferous strata with an interbedded phosphatic nodule deposit, occurring ten chains north-west of the Point Ronald Beds, and have been regarded as of Janjuki (Upper Oligocene to Miocene) age (Baker, 1944, p. 88 and 1945b).

The *Gellibrand Beds* are composed of thick, dipping, fossiliferous clays with occasional limestones, argillaceous limestones and a clay bed showing interformational contortion (near top of Gellibrand Beds in Fig. 2). These beds outcrop at intervals (between landslide debris) from $\frac{3}{4}$ of a mile north-west of Point Ronald to the south-east end of Gibson's Beach (see Baker, 1944, Fig. 2, p. 78).

The *Glenample Beds* are clays and argillaceous limestones with occasional fossils ; they are more or less horizontal, and are exposed in cliff sections between Glenample Steps (see Baker, 1944, Fig. 1, p. 78), $7\frac{1}{2}$ miles south-south-east of Port Campbell, and the Sherbrook River, $3\frac{3}{4}$ miles east of Port Campbell. Dips of 1° and less, cause these beds to pass under the Rutledge's Creek Beds.

The *Rutledge's Creek Beds* are fossiliferous clays, limestones and argillaceous limestones, which are more or less horizontal and occur in the cliff sections east and west of the mouth of Rutledge's Creek, $3\frac{1}{4}$ miles east of Port Campbell.

The *Port Campbell Beds* are clays and argillaceous limestones with occasional fossils; they extend more or less horizontally for four miles west and three miles east of Port Campbell.

The *Peterborough Beds* are the limestones occurring in the axis of a broad, open syncline in the Curdie's Inlet region at Peterborough; they overlie clays of the Port Campbell Beds.

The *Covered Interval* in Fig. 2, represents the gap in the exposed sequence of Tertiary Beds, due to post-Miocene erosion by the ancestor of the Gellibrand River: the area is occupied by a thickness of at least 300 feet of Pleistocene dune limestone.

At the top of the column in Fig. 2, the post-Miocene clays and the Pleistocene dune limestones are included individually to show their separate thicknesses; actually they were formed, in part, at the same time. Late Cainozoic sands, grits and gravels along the Gellibrand watershed, probably also belong, in part, to this age.

The portion of the column (Fig. 2) occupied by the Heytesbury Formation, represents Late Oligocene and Miocene sedimentation in this area. Various members of this formation have been correlated (Baker, 1944) with Janjukian rocks (Upper Oligocene to Lower Miocene), with Balcombian rocks (Middle Miocene) and with Cheltenhamian rocks (Upper Miocene) that occur elsewhere in Victoria, the classification of Victorian Tertiary rocks according to Singleton (1941) being followed.

Teichert (1947b) has recently described a new nautiloid from the phosphatic nodule deposit in the Clifton Beds of the Heytesbury Formation, as *Deltoidonautilus bakeri*, a form most closely allied to *D. deluci* (d'Archaic) occurring in the Lower Eocene, Sind, India. No representative of the genus *Deltoidonautilus* is known to occur in strata younger than the Eocene, but in the Clifton Beds, it is associated with a Lower Miocene to Upper Oligocene fauna, and is probably a remanié fossil in these deposits. A new species of *Aturia* (Teichert, 1947b) from the same deposit, may also be derived.

These derived fossils indicate that somewhere in the Lower Miocene—Upper Oligocene terrane, Eocene deposits were exposed. The state of preservation of the fossils suggests exposure to submarine wave action rather than to the action of subaerial agents, so that Eocene rocks may have formed parts of the Lower Miocene—Upper Oligocene sea floor, on which phosphatic nodules were being precipitated. No evidence of an erosion break between the Eocene and the Lower Miocene—Upper Oligocene has been located in the field, although if one did occur, it might be masked by the covered interval. The matrix in the whorls of *Deltoidonautilus bakeri* cannot be specifically matched with that of any of the Eocene beds exposed in the Princetown-Moonlight Head district; not only has there been replacement by phosphatic and ferruginous material but also some infiltration of the limestone-gritty matrix that characterises the phosphatic nodule deposit.

LATE CAINOZOIC

PLEISTOCENE

Dune limestone, referred to the Pleistocene period, is confined to the western portion of the area, occurring on either side of the mouth of the Gellibrand River, and extending inland from the coast for up to approximately $\frac{3}{4}$ of a

mile. The characteristics and mineralogy of the deposit have been described previously (Baker, 1943a and 1943b).

POST-MIOCENE

Post-Miocene sands, grits and gravels are widespread in the area. Wilkinson (1865) described very coarse quartz pebble drift, from approximately 10 miles up the Gellibrand valley, as containing well-rounded pebbles of granite porphyry, mica schist, quartz rock and various coloured stones, some like lydian stone (a black variety of jasper, used as a touchstone by jewellers).

Gold was found in the quartz pebble drift, but not in payable quantities. Murray (1877) referred to this deposit as a heavy gravel which rested on the Mesozoic rocks, while Kenny (1938) recorded pebbles from the deposit as consisting of waterworn quartz, jasper, cherts and fragmental porphyry pebbles up to one foot in diameter. These porphyry pebbles were stated to be like the rocks forming Devonian dykes in the Grampians, some 70 miles away, and Kenny suggested the possibility of their having been transported from this source by ice.

Comparable pebbles are found on the dune limestone south-east of Rivernook House (Fig. 1) but were carried there by aborigines; many of the pebbles have been broken open, and some subjected to secondary chipping. Similar pebbles are scattered over some of the beaches north-west of Pebble Point in the bays between Point Pember and Buckley's Point and between Point Margaret and Buckley's Point. On the beach immediately north-west of Pebble Point, near the fault F_2 shown in Fig. 1, storm waves have accumulated a cobble-pebble beach of very varied constituents. The rock types represented include reef quartz, quartzite, flint, red and black jasper, green and red jasperised porphyries, andesite, rhyolite (sometimes with inclusions of other volcanic rocks), hornfels, olivine basalt and ironstone. Pebbles of some of these rock types are also found on beaches as far away as those near Deany Steps (Baker, 1943b, p. 380) approximately 10 miles distant in the north-west. On the beach at the head of the Devil's Kitchen, similar pebbles and fragments of Jurassic and Eocene rocks have been cemented into a recent conglomerate (Plate IV, Fig. C).

The origin of these pebbles is problematical; those on the beaches were no doubt re-sorted from the Late Cainozoic pebble deposits, although basaltic types were probably brought down independently from the basalt plains lying some thirty miles to the north of this area. The other volcanic types and the quartzose rocks were probably weathered out from the conglomerates in Jurassic rocks, into which they had been gathered from the Jurassic terrane. From the Jurassic, they became added to both the Pebble Point Beds in Eocene times, and to the superficial deposits in later Cainozoic times. Wilkinson (1865) has recorded pebbles of similar petrological types in the Jurassic rocks of the Otway coast, and there is little doubt that the Jurassic bedrock of the Moonlight Head district was the source for most of the pebbles found in the later rocks. There is no evidence to support Kenny's suggestion of possible transportation by ice from the Grampians; the maximum size of the cobbles and boulders (a foot or so across) does not exclude the more likely possibility of river or ocean current transport.

The widespread gravels, referred to as 'light bouldery washes and gravels' by Stirling (1898), were stated to have associated, slightly auriferous sandy clays, and to occur in the Gellibrand River valley and flanking the north-west spurs from the Cape Otway sandstone ridges (see Fig. 4). Stirling regarded them as being partly derived from the abrasion of the quartz veins intersecting the Mesozoic sandstones. Similar gravels extend southerly, from the area

referred to by Stirling, down to the Lower Gellibrand-Moonlight Head district, where they occur capping the Jurassic and Eocene hills and also occur in some of the gullies. They have been worked for alluvial gold (Stirling, 1899) in allotments 23 and 24 in the parish of Wangerrip, and also in the gullics south of Neave's farm (see Fig. 1), but with no important yields.

Both Murray (1877) and Stirling (1898) regarded these deposits as being comparable in age and character with similar Upper Cainozoic deposits flanking the South Gippsland Jurassic ranges, while Murray (1877, p. 130) also correlated them with 'the oldest (Lower Pliocene) drift period of the Ballarat goldfield.' There is little evidence to prove conclusively either the age or the origin of these deposits in the Moonlight Head district. They are undoubtedly post-Eocene, because in the hinterland near The Gable (Fig. 1), the quartz drift occurs spread out on top of eroded clays and ferruginous beds belonging to the Wangerrip Formation. Some of the gravels are post-Pleistocene, because quartz gravels up to 30 feet thick flank the Pleistocene dune limestone on the south wall of the Gellibrand River valley, about 200 yards west of north from Rivernook House, here they are approximately 75 feet above the present bed of the Gellibrand River.

Similar quartz gravels and sands extend as a thin veneer over the Mesozoic rocks from the Beech Forest area, some twenty miles to the north-east, down the highway through Ferguson, Wecaprounah, Wyelangta, Stalker, Laver's Hill and on to Princetown (see Fig. 4), i.e., along the Main Dividing Ridge in the south-west Otway Ranges. At Princetown township, the gravels are post-Janjukian, since they rest on limestone of this age, forming the small hill in the Gellibrand River-Latrobe Creek flood plain, on which Princetown stands (Baker, 1945b, p. 92). Along the lower reaches of the Gellibrand River, recent gravels, which contain white reef quartz pebbles up to 3 inches across, are approximately 20 feet above river level on the north bank of the river, $\frac{3}{4}$ mile east of Rivernook House. In parts, they are associated with sands and clays, the deposits reaching a thickness of some 25 to 30 feet, and being, at this locality, relatively recent fluvial deposits. Such sediments have been re-sorted from the older quartz gravels occurring at greater elevations in the Otway Ranges.

Occurrences of fluvial gravels at heights of 75 feet on the south bank and 20 feet on the north bank, represent old river terrace deposits, and the variations in height above present river level are possibly to be correlated with eustatic changes of sea level in Quaternary times.

Summing up the available evidence on the quartz gravels in the Moonlight Head district, it would appear that, prior to the extensive spreading out of these deposits, the terrane of the Moonlight Head-Gellibrand River area was one in which Mesozoic, Eocene and Miocene (Janjukian) rocks were exposed. Extensive erosion occurred in Post-Miocene times, of an area rich in quartz reefs, associated with granitic intrusions and thermally altered contact rocks, which lay somewhere to the north, and is now under the lava plains of Western Victoria, or somewhere to the south, and now under the Southern Ocean. Torrential conditions would be necessary to transport the larger, heavier constituents of the gravels from their source and spread them out over wide areas which were probably of low relief.

These conditions must have been initiated as far back as early Eocene times, to account for (1) the heavy, reef-quartz rich gravels and grits found in the Pebble Point Beds (cf. Plate IV, Fig. A), and (2) the presence in the Eocene of runs of conglomerate. Pebbles of rock petrologically similar to those in the Eocene conglomerate are found higher up the Gellibrand River, where they were deposited on an erosion surface in the Jurassic rocks at an apparently

much later period of the Cainozoic. Furthermore, similar pebbles occur in some of the gravels now only 20 and 75 feet above river level in the lower reaches of the Gellibrand River. The very well rounded character of the larger pebbles in the gravels and conglomerates of various ages in the area, is probably to be traced back to pre-Jurassic times, because those incorporated in the Jurassic sediments are just as well rounded.

The associated, somewhat finer quartz grits that occur on the tops of the spurs inland from The Gable and inland from Oliver Hill (see Fig. 1), are principally made up of angular to sub-angular grains of reef quartz up to 6 mm. long, with the finer fraction (under $\frac{1}{4}$ mm.) mainly angular quartz with but few rounded grains and rare felspar. Heavy mineral grains are rare in these parts of the grits, and represented by magnetite, blue and brown tourmaline, zircon, red and yellow rutile, sillimanite, ilmenite, leucoxene, anatase, limonite and andalusite.

Patches of quartz sand occur localised in places on the spurs. One such patch on the north side of the old road north of Oliver Hill is over 10 feet thick, and contains the grade sizes illustrated in the histogram in Fig. 3.

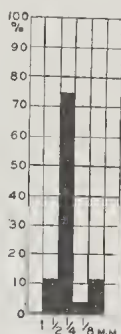


Figure 3. Histogram of late Cainozoic sand from north of Oliver Hill.

The sand is well-sorted, with the greatest percentage of grains in the $\frac{1}{4}$ to $\frac{1}{2}$ mm. fraction, thus contrasting greatly with the poorly-sorted grits and gravels. The heavy minerals in this fine quartz sand are magnetite, blue and brown tourmaline, zircon, ilmenite, leucoxene, red and yellow rutile, anatase, andalusite, cyanite, green spinel, staurolite and hornblende. The varietal heavy mineral species in this sand are generally comparable with those in the coarser sediments, but they are of much finer grade size than those in the grits and contain rare grains of additional mineral species unrepresented in the sampled portions of the grits.

RECENT

The Recent deposits in the Moonlight Head area are fluvatile, estuarine and beach deposits, represented by the alluvial and marine sediments along the floor of the Gellibrand River valley, the sand dunes on the east side of the mouth of the Gellibrand River, the sand, pebble, cobble and boulder beaches (sometimes cemented to form conglomerate) and the landslide material along the coastal stretches from the vicinity of The Gable north-west to Point Ronald (see Fig. 1).

In the broad, swampy flats of the Gellibrand River, Wilkinson (1865) recorded extensive beds of oyster shells, *Cerithium* and *Arca* in raised estuary deposits, while Murray (1877, p. 129) recorded the deposits as consisting of mud and sand containing recent marine shells. The depth of the alluvium in the valley floor of the Gellibrand River, is of the order of 20 feet or so; a well sunk on Till's Flat, near Princetown township, passed through approximately 20 feet of silt and then struck quartz gravel like that forming the capping of the hill on which Princetown is built.

Landslide material on the beaches consists of large blocks of Eocene ferruginous beds incorporated in fine-grained material derived from the Eocene clays. The sand dunes near the mouth of the Gellibrand River are relatively fine-grained and are only partially fixed.

The boulder beaches are uncommon, and have considerably greater angles

of rest on wave-cut platforms than the sandy beaches. Among the normal quartz sands on the beaches streaks of heavy black sands are frequently met with at certain periods of the year. They are most extensive on Marie Gabrielle Beach in the environs of the mouth of Wreck Creek, and are like those recorded from other Victorian beaches (Baker, 1945a). The principal heavy constituents are the black iron oxides, mainly magnetite in the portion sampled, but with some ilmenite. The coloured, translucent and colourless heavy minerals are represented by zircon, colourless, brownish and pink garnet, foxy-red and yellow rutile, staurolite, leucoxene and topaz. The majority of the grains are particularly well-rounded and polished, only a few zircons and occasional magnetite grains exhibiting crystal faces. The mineral grains have obviously survived several periods of erosion, transportation and sedimentation, the source rocks being manifold.

Australites

Of fifteen australites located in the Moonlight Head district (see *A* on map, Fig. 1), one was found on the cliff edge near the Old Racecourse, and the remainder on the surface of an old, little used road which runs near the coast from Neave's farm to Rivernook House.

Nine of the australites were complete or nearly complete, and six were fragments. The complete and nearly complete forms occurred on the surface of the ground in the normal, stable position of rest for australites generally, i.e., with the anterior surface facing upwards.

The weights, specific gravity values and dimensions of these australites are set out in Table 2. Specific gravity values were obtained by the method of weighing in air and in water on the chemical balance, using distilled water of temperature 18°C.

TABLE 2.

	Australite Shape	Weight in gms.	Sp. Gr.	Diameter in mm.	Depth in mm.	Length in mm.	Width in mm.	Flange width in mm.
1.	Button ..	4.455	2.421	20	12	—	—	4
2.	Button ..	2.395	2.410	19	8	—	—	3
3.	Button ..	1.966	2.409	16	8	—	—	3
4.	Lens ..	2.133	2.402	15	7.5	—	—	—
5.	Lens ..	1.838	2.418	15	7	—	—	—
6.	Lens ..	0.837	2.412	11	6	—	—	—
7.	Oval ..	2.181	2.421	—	9	15	13.5	—
8.	Dumb-bell (half)	0.931	2.412	—	5	16	9	1
9.	Button fragment	2.150	2.416	—	—	—	—	4
10.	Flange fragment	0.240	2.400	—	—	—	—	4
11.	Boat ..	25.869	2.404	—	18	41	28	—
12.	Core ..	2.536	2.435	—	11	—	—	—
13.	Aberrant form (half)	3.223	2.400	—	8	29	—	—
14.	Nondescript fragment	0.164	2.412	—	—	—	—	—
15.	Nondescript fragment	0.134	2.401	—	—	—	—	—

The average weight of the complete and nearly complete forms of these australites is 4.912 grams, and for a total weight (51.052 grams) of australite glass collected, the average specific gravity is 2.411. This value is slightly greater than the average specific gravity (2.397) for the Port Campbell australites which are found 12 to 15 miles to the north-west (Baker, 1937 and Baker and Forster, 1943). Since the specific gravity of australite glass is a function

of the silica percentage, the inference is that the Moonlight Head australites are rather more basic than those occurring in the Port Campbell strewnfield.

The australites from the Moonlight Head district display characteristic external and internal features of australites described from many localities in Australia, and require little further comment. Flow ridges on the anterior surfaces of specimens 1, 2, 3, 6 and 7 (Table 2) are concentric, those on specimen 8 are clockwise spiral in arrangement. The specimens on the whole are not quite as well preserved as the Port Campbell australites.

Physiography of the Area

SURFACE TOPOGRAPHY

The general topography of the area embraced by the map (Fig. 1), contrasts sharply with the gently rolling nature of the Port Campbell plain (Baker, 1943b) to the north-west, in being of a rugged character and relatively deeply dissected by short, narrow gullies (Plate I, Fig. B) which drain into the Gellibrand River, in the central portions of the area, or into the sea, in the south. The region is one with an average annual rainfall of 35 inches as determined from records kept over 34 years at Rivernook (W. S. Watt, 1937), and the short, narrow gullies only flow intermittently.

The area occupies the south-western limits of the Otway Ranges of Jurassic sediments, which are here flanked by Eocene and younger Cainozoic deposits. The principal features of the hinterland in the Moonlight Head district are the narrow, flat-bottomed, relatively steep-walled valley of the Gellibrand River (Plate II, Fig. E) and a main ridge trending more or less east and west between the Gellibrand River and the sea. This ridge constitutes the western end of the Latrobe Range, and was referred to by Wilkinson (1865) as the Moonlight Head Range; it was along this ridge that part of the Cape Otway to Warrnambool survey track was cut in 1863-64. The ridge constitutes the main watershed of the area, separating the narrow streams flowing north-west into the Gellibrand River, from a number of short streams with somewhat deeper valleys, including Wreck Creek, Wall's Gully and Freetrader Creek, which flow generally south into the sea.

The Gellibrand River and its tributaries drain the northern to south-western flanks of the Otway Ranges (Fig. 4) and according to Wilkinson (1865, p. 23) the course followed by the Gellibrand River, from a point north of Cape Otway down to the sea, may be taken as the approximate western boundary of the Mesozoic rocks of the Cape Otway country. Three miles inland from the coastline, the Gellibrand River, flowing down from the north, at Lower Gellibrand (see Fig. 1), takes a sharp sweep westerly across the geological boundary between Jurassic and Tertiary rocks, and flows west and north-west for some 8 or 9 miles before entering the sea at Point Ronald. The reason for this is obscure. It could possibly be a result of faulting, as in the upper parts of its course at Gellibrand, where Kenny (1938) found that the Gellibrand River and the tributary in line with it (i.e. Love's Creek, see Fig. 4) apparently followed along the trend of a Tertiary fault with a downthrow to the south-east of about 150 feet. If faulting caused the Gellibrand to swing westerly at Lower Gellibrand, an east-west fault would have to trend through Lower Gellibrand along Ware's Creek, probably as a small trough fault associated with that at Point Bell and Pebble Point. There is, however, no direct evidence to substantiate this suggestion, and another alternative is the development of a rising coastline in the south, which may have caused the Gellibrand to swing west and north-west, but there is again no supporting evidence. Yet another possibility is that the early course of the Gellibrand River in its lower reaches from Lower

Gellibrand to the sea, was originally determined by the north-westerly slip-off slope developed on the Eocene rocks as a consequence of their initial dip of 5° north-westerly, and the change in course is partly to be explained in terms of differential hardness between the relatively homogeneous Jurassic sediments (mainly arkoses) and the non-homogeneous Eocene sediments (grits, ferruginous sandstones, clays, etc.). At all events, it is evident that the directions of flow of tributaries to the Gellibrand River have a general parallelism with one another, in a direction also trending parallel with the north-westerly slip-off slopes, i.e., in the direction of dip of the Eocene sediments.

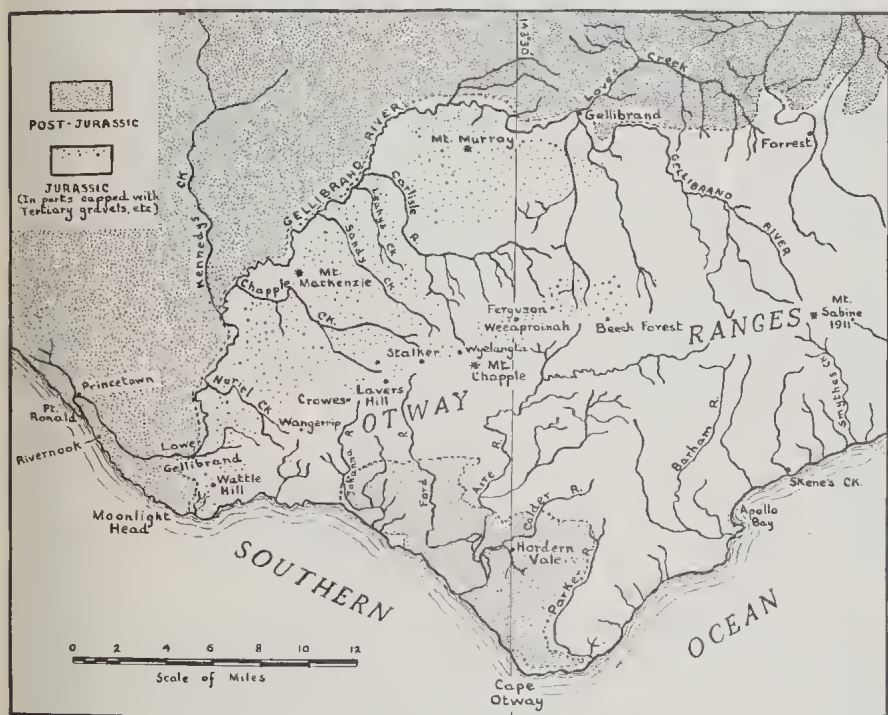


Figure 4. Map of the Cape Otway—Moonlight Head region showing drainage systems and general geology (simplified). Based on 4 mile Strategic Series, Australia: Colac (second edition, 1942) and 8 miles to 1 inch Geological Map of Victoria.

The general features of the valley of the Gellibrand River, from Lower Gellibrand to the sea near Princetown, result from a combination of geological and past geographical factors. The flat-bottomed valley floor occurring between steep valley walls, is a consequence of downward deepening during a period of rejuvenation, followed by alluviation during a period of still-stand, river silts being deposited by geologically recent flooding of the lower reaches, on top of older quartz sands and gravels brought down when the gradient of the river was steeper.

Since the older sands and gravels also occur in ancient terraces, at heights of 20 and 75 feet above present river level, it is evident that there have been several variations of sea level relative to land level. It is considered that such oscillations in sea level are most likely attributable to eustatic variations during the Quaternary glacial and interglacial periods. During one of the later

world-wide interglacial epochs, the Gellibrand River was evidently estuarine for some little distance from its present mouth, as shown by the muds and sands with marine molluscs in the floor of the present flood plain. With lowering of sea level in earlier world-wide glacial epochs, rejuvenation near the river mouth resulted in downward deepening of the valley and the scouring out of much of the earlier-formed gravels, but left residual patches high up on the valley walls, as near Rivernook House, as well as small residual hills nearer the mouth, as at Princetown.

In addition to the effects of eustatic variations in sea level, and partial control of its direction of flow by slip-off slopes in the Eocene grits and clays, the history of the Gellibrand River has been further complicated by the growth across its mouth of Pleistocene dunes (now consolidated), and Recent dunes (unconsolidated and only partially fixed in position). While, therefore, the river has cut into the harder Pleistocene dune rock right at its mouth, forming river cliffs some 270 feet high on the western bank, recent dunes have been built up to 50 feet on the eastern bank. The river has had actively to cut down through the harder dune rock in order to keep the mouth open, and to maintain its already well-established course. Thus is explained the present narrowness of the mouth of the Gellibrand River (approximately 50 feet), compared to its considerable length (50 to 55 miles) and the considerable volume of water discharged into the sea. The long, narrow, flat valley floor of the river is probably to be explained in similar terms, the harder bar of Pleistocene dune limestone across its mouth, being principally responsible for the periodical flooding and alluviation that occurs upstream as far back as Gellibrand (see Fig. 4), situated some thirty miles from the mouth.

On the flat, narrow floor of the valley of the Gellibrand River, approximately five miles along the river course from its mouth, there are other remnant features testifying to an earlier and more vigorous period of erosional activity, and indicating an epoch when sea level was lower during a former world-wide glacial epoch. These are a partially buried, cut-off spur, and two partially buried river-cut spurs still attached to the northern valley wall (Plate 11, Fig. E).

The partially buried, cut-off spur, developed by circumdenudation on the valley floor during meander swinging, is elliptical in plan, about 150 yards long, and appears conical in end-on aspect. The eastern example of the two partially buried river-cut spurs has a small saddle two thirds of the distance along from the end nearest the Gellibrand River; this small saddle, the river-cut spurs and the cut-off spur are considerably lower than the summits of the valley walls and they represent the remnants of the earlier meandrine course of the river in its narrow valley. They are now partly buried by alluvium which flanks them and so they form prominent features in a narrow, flat-bottomed valley, which is here only about 20 chains wide on the average, and as narrow as 8 to 10 chains in the narrowest parts.

The river flats near the mouth, however, are rather more extensive in the neighbourhood of Princetown township, for here the Gellibrand River is joined by Latrobe Creek (see map, Baker, 1943a), which flows in from the west and drains a terrane composed mainly of soft Miocene clays, in which there is a marked hummocky topography due to frequent slumping of the clays.

A characteristic feature of the streams flowing south from the main watershed of this area to the sea (Fig. 1), is the height of their mouths above sea level. They either flow as small waterfalls over cliffs some 20 feet high in the Jurassic rocks, or else flow over less steeply inclined rock surfaces (determined by bedding planes in the Jurassic) in a series of cascades. They thus have hanging valleys, due to the dominance of marine erosion over stream erosion at the mouths.

COASTAL TOPOGRAPHY

The coastline of the Moonlight Head district is bold and rugged. The indented character of the coastline is plainly evident from the aerial photographs (Plate I) and from photographs illustrated in Plate II (Figs. C, D and F), Plate III and Plate IV (Figs. D, E and F).

Changes in the nature of the cliff profile along the coastline are due mainly to the differential erosion of beds varying in hardness, as well as in chemical and other physical properties. Steeply sloping, somewhat terraced cliffs of marine and subaerial erosion are developed in the alternating grits and clays of the Wangerrip Formation, as shown in Plate IV, Fig. E, but in the Jurassic, where arkoses predominate, the rock formation is more homogeneous and calcareous, so that cliff profiles are nearly vertical, being sheer in parts, as seen in the lower portions of the cliffs at Moonlight Head (Plate II, Figs. D and F) and elsewhere.

Caves are uncommon along this coastline, compared to their frequency along the limestone coastline situated a few miles further to the north-west (Baker, 1943b). A few small caves high up on the western side of Pebble Point (Plate IV, Fig. E), impart a pock-marked appearance to the Eocene clays in the cliffs: they result from subaerial erosion. A much larger cave in the Jurassic rocks at the Devil's Kitchen (see Fig. 1), results from wave erosion and has been cut at storm-tide level along a prominent joint plane.

Slump terraces and erosion amphitheatres, normally rare and so far undescribed along the Victorian coastline, are characteristic of the cliffed coastline between Rivernook House and Moonlight Head, more particularly where the clays of the Wangerrip Formation occur in the upper parts of the cliffs. Slumping of portions of these Eocene rocks has resulted in a stepped or terraced formation on the tops of some of the marine-cut cliffs (see skyline in Plate II, Fig. C). Inland cliffs, formed at the landward extremities of areas so affected, are steep, 200 feet high in parts, and up to a quarter of a mile inland from the marine cliffs in parts of the area.

The formation of the slump terraces is ascribed to processes similar to those outlined by Sharpe (1938). They result from the lubrication of slip planes in the Eocene clays by rainwater. Several units slump with a backward rotation, the slipping occurring on deep-seated, curved surfaces giving rise in parts to at least four backward-sloping blocks, tilted into the slope of the cliff tops. Such features are best evident at the head of Dilwyn Bay (Plate I, Fig. A) on the steep slopes above the high marine cliffs. Here individual slump terraces are up to 40 feet high, and a broken series of them are concentric in plan, paralleling the outline of the shores of Dilwyn Bay. The terraces have been formed under conditions favourable to sliding, owing to the presence of competent layers (grits, ironstones and ferruginous sandstones) and incompetent layers (carbonaceous and copiapite-bearing clays) comprising the Wangerrip Formation, in an area subject to frequent coastal showers, occasional heavy storms and general wetting by wind-driven spray. The back slopes of the slumped blocks, i.e., the competent layers which have slid over the clays, principally trend north-east, this being the direction of strike of the Eocene deposits; slickensided surfaces are frequently associated with the planes of sliding in the clays.

Because the slumping occurs prevalently from within twelve chains of the coastline to the edges of the marine-cut cliffs, it becomes a potent factor in retrogradation of the coastline by marine abrasion. The slumped block nearest the edge of the marine-cut cliff invariably falls either directly into the sea or on to the wave-cut platform, where the slumped material is rapidly abraded and

swept away by tidal action. Two types of cliff profiles thus result from two different processes: marine-cut cliffs are developed by the normal processes at work during the attack of the sea upon the land, and they are steep and almost perpendicular in parts; inland cliffs result at higher levels and at short distances inland as a consequence of the slumping processes. In the intervening area, the surface either slopes less steeply, or is broken by the formation of slump terraces, some of which are quite regular, but others are so irregular as to produce a hummocky topography.

The erosion amphitheatres result from processes similar to those producing the slump terraces; in fact they develop concomitantly with them, and represent large landslip scars (see Fig. 1). By a process of natural quarrying, headward sapping of the cliff tops along parts of the coastline forms scarps in the soft, incompetent clays, over which the competent grits and ferruginous sandstones slip. Considerable tracts of land glide seawards from the upper portions of the coastline, so that the steep cliffs, up to 200 feet high, develop backwards from the coastline. The seaward limit of the erosion amphitheatres is sometimes almost at beach level (right-hand examples in Plate I, Fig. A and Plate III, Fig. A), but some are perched high up on the cliff tops (Plate III, Fig. A shows the initiation of a small perched erosion amphitheatre at Point Margaret, on left-hand side). The perched erosion amphitheatres are more usually developed where the Jurassic cliffs are higher and capped with Eocene sediments.

The best developed erosion amphitheatres along the Moonlight Head-Gellibrand River mouth portion of the coastline, occur on the north-west side of Buckley's Point (right-hand side of Fig. A, Plate III), at the western end of Marie Gabrielle Beach, near Point Lutton (right-hand side of Fig. A, Plate I), and south-west of the Old Racecourse near Moonlight Head (left-hand side of Fig. B, Plate I). The floors of the erosion amphitheatres are usually hummocky and ridgy, and those with floors grading down almost to beach level, have had considerable amounts of the slumped debris removed by marine action; sometimes, however, the seaward edges of the floors of such erosion amphitheatres are temporarily protected from wave action by the growth of beach sand-ridges.

Landslides in the Eocene rocks must have occurred with considerable frequency during recent times to have produced such marked and well-developed features as the slump terraces and erosion amphitheatres. Additional effects of the slumping processes are evident today in the large quantities of landslip material that occur on parts of the beaches and on the wave-cut platforms at the bases of the steep, marine-cut cliffs. Where such relatively recent landslide material occurs in sufficiently large amounts, temporary minor headlands result, and these show up to advantage in aerial photographs which take in Point Pember (see Plate IV, Fig. D) and the south-south-east side of Buckley's Point (Plate III, Fig. B—on left). Elsewhere, the slumped material partially buries the marine-cut cliffs, resulting in less steep profiles (as in central portion shown in Plate III, Fig. A).

Wave-cut platforms in the Moonlight Head district are widest and best developed off headlands formed in the Jurassic rocks (Plate II, Fig. D and Plate III, Fig. B); they are of rare occurrence in the Eocene rocks, where sandy beaches or talus heaps are more usual at the cliff bases. The wave-cut platforms in the Jurassic rocks are generally broken into and disconnected by gulches, formed where more rapid marine erosion has gone on along prominent joint planes, but they are continuous for considerable distances along Marie Gabrielle Beach, where they are fringed with narrow, sandy beaches (Plate IV, Fig. F).

A feature of some parts of the wave-cut platforms, e.g. at the base of The Gable (Fig. 1), is the presence of barriers, some six to ten feet high, at their seaward extremities. These barriers provide partial protection against low- and mid-tide erosion, but are covered by high and storm tides. They apparently result from slight variations in the resistance of the Jurassic arkoses, probably because of greater amounts of calcareous cement. The small rock pools in the wave-cut platforms occupy the positions from which rounded and elliptical calcareous concretions have been broken out, while the larger rock pools represent either enlargements of the initial depressions left by the removal of the concretions, or more probably differential erosion of less highly cemented portions of the Jurassic arkoses between joint planes along which secondary cementation has been prevalent.

Sink-holes are neither as large nor as numerous as those developed in the Tertiary limestone coastline (Baker, 1943b) to the north-west of the Moonlight Head district. Only one has been noted, and it is funnel-shaped, about twelve feet across at the top, and occurs in Jurassic arkose at a small headland situated immediately north-east of Moonlight Head.

The shoreline profile is generally a youthful one on a coastline suggesting a compound character. Features indicative of submergence dominate those indicative of emergence, and retrogradation dominates progradation. As a result, steep, bold sea cliffs in both Jurassic and Eocene rocks, are dominant features in the landscape, with wave-cut platforms best represented at the bases of the Jurassic cliffs, and ledge-like structures best formed at various levels in the Eocene cliffs, the homogeneity or otherwise of the various rock types, exercising the control in this respect. Features indicating progradation are not pronounced, and are represented by the wider sandy beaches on the south-east side of the mouth of the Gellibrand River, in the vicinity of the Recent sand dunes, and by the formation of a bayhead beach ridge about 200 yards long and up to 25 feet high in Dilwyn Bay (Plate II, Fig. C).

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